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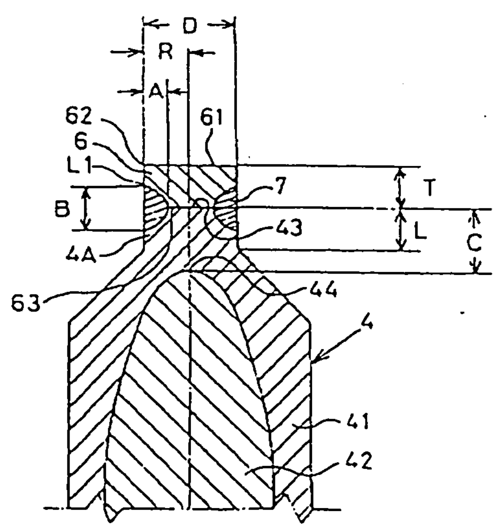
(54) A spark plug.

(57) In a spark plug, a nickel-alloyed center electrode has a front end which has a front forming a spark gap with a ground electrode by way of a noble metal firing tip. The noble metal firing tip is secured to a front end surface of the constricted end by applying a laser beam welding to the surface around the circumference of the external interface between the front end and the firing tip so as to form a wedge-shaped welding solidification portion which extends into the centre electrode.

Fig. 2



EP 0 575 163 A1

This invention relates to a spark plug for an internal combustion engine in which a firing tip is secured to a front end of a center electrode and a method of manufacturing such a spark plug.

In a center electrode of a spark plug for an internal combustion engine, a composite structure has been used in which a heat-conductive core (Cu) is embedded in a heat-and erosion-resistant clad metal (nickel-based alloy) as shown in Japanese Patent Publication No. 59-2152. According to the Japanese Patent Publication No. 59-2152, a noble metal firing tip is further bonded to a front end of the clad metal by means of electric resistance welding so as to improve its resistance against spark-erosion. After completing the electric resistance welding, the firing tip and the front end of the clad metal are milled respectively to make them diametrically even.

With this method, the electric resistance welding heats and presses the firing tip so as to make the edged corner of the firing tip rounded. As a result, a higher voltage is required for the spark plug to discharge between its electrodes. In order to recover the original edged corner, it is necessary to mill the firing tip which wastes the expensive noble metal.

In Japanese Patent Publication No. 63-57919, a hole is provided at a front end surface of the clad metal, and the firing tip is placed within the hole to apply a laser beam welding from the front end of the clad metal to the firing tip.

With this method, it is necessary at the time of the laser beam welding to place the firing tip deep enough into the hole to positively secure the firing tip against inadvertent removal. This requires an increased quantity of the noble metal which makes the firing tip costly.

According to one aspect of the present invention there is provided a spark plug comprising a ground electrode and a centre electrode having a front end with a firing tip welded thereto, the firing tip forming a spark gap with said ground electrode, characterised by weld extending around the circumference of the external interface between said front end and said firing tip and into said centre electrode at said interface.

According to another aspect of the present invention there is provided a method of manufacture of a spark plug with a ground electrode and a center electrode having a front end with a firing tip thereto and forming a spark gap with said ground electrode, wherein said method includes the step of welding said firing tip to said front end and is characterised by carrying out the welding around the circumference of the external interface between said front end and said firing tip such that weld extends into said centre electrode at said interface.

Advantageously the weld is a laser beam weld, an argon weld or an electron beam weld.

Preferably, said front end is constricted as compared with the rest of said centre electrode.

Advantageously said firing tip is of generally similar cross-section to the surface of said front end to which said firing tip is welded.

Preferably in said longitudinal cross section said weld has a wedge shaped cross section.

Advantageously said firing tip is made of a noble metal. With the noble metal firing tip welded to the front end, it is possible to decrease the required spark voltage without sacrificing a good ignitability with a minimum amount of spark erosion and with a reduced amount of noble metal. Thus the service life can be extended and the cost lowered.

Preferably, where D is a diameter of said firing tip, T is a thickness of said firing tip, L is a length of said front end of said centre electrode, A is a depth of penetration of said weld, R is a radius of said firing tip, and B is a width of said weld measured at an outer surface of both said front end and said firing tip, and

wherein a dimensional relationship between D, T, L, A, R and B is as follows:

$0.5 \text{ mm} \leq D \leq 1.5 \text{ mm}$,
$0.3 \text{ mm} \leq T \leq 0.6 \text{ mm}$,
$0.2 \text{ mm} \leq L \leq 0.5 \text{ mm}$,
$R/3 \leq A \leq R$,
$0.3 \text{ mm} \leq B \leq 0.8 \text{ mm}$.

With the dimensional relationship defined as above, it is possible to decrease the required spark voltage with a smaller amount of noble metal, and ensuring a good ignitablity with a minimum amount of spark erosion.

Preferably, laser beam welding is applied intermittently to the outer surface of both the constricted end and the firing tip in order to partially overlap neighboring shot spots of the laser beam welding, each front end limit of the shot spots being away from a front end surface of the firing tip by at least 0.1 mm.

With the neighboring shot spots partially overlapped and the front end limit of the shot spots being away from a front end surface of the firing tip by at least 0.1 mm, it is possible to positively maintain the firing tip secured to the front end of the center electrode without falling off the center electrode inadvertently at the time of the spark discharging in which the spark plug undergoes the high pressure and highly heated environment. With the edged corner of the firing tip remaining intact, it is possible for the spark plug to discharge with a minimum voltage.

Preferably the center electrode comprises a heat-resistant clad metal and a heat-conductive core embedded in the clad metal, and a front end of the heat-conductive core is either in thermally transferable contact with a rear end surface of said firing tip or within 1.5 mm of the rear end surface of said firing tip.

With the above structure, the heat is preferably transferred from the firing tip to the heat-conductive core to prevent the temperature of the firing tip from excessively rising. This makes it possible to reduce the voltage required to discharge between the elec-

trodes with a minimum amount of the spark erosion even when a thinner firing tip is used.

In order that the invention may be more readily understood the following description is given, by way of example only, with reference to the accompanying drawings, in which:

Fig. 1 is a plan view of a spark plug, with its left half sectioned;

Fig. 2 is a longitudinal cross sectional view of a front portion of a center electrode;

Fig. 3 is a perspective view of the front portion of the center electrode;

Fig. 4 is a graph showing a relationship between a diameter of a noble metal firing tip and a spark gap increment;

Fig. 5 is a longitudinal cross sectional view of the front portion of the center electrode when a thickness of the firing tip is less than 0.3 mm;

Fig. 6 is a graph showing a relationship between a penetrated depth (A) of a welding solidification portion and number of operating cycles required for the firing tip to fall off the center electrode;

Fig. 7 is a graph showing a relationship between a spark gap increment and a distance from the firing tip to a heat-conductive core;

Fig. 8 is a view similar to Fig. 2 according to a first modified form of the embodiment of Fig. 2;

Fig. 9 is a view similar to Fig. 2 according to a second modified form of the embodiment of Fig. 2;

Fig. 10 is a view similar to Fig. 2 according to a third modified form of the embodiment of Fig. 2; and

Fig. 11 is a view similar to Fig. 2 according to a fourth modified form of the embodiment of Fig. 2;

Referring to Fig. 1 which shows a spark plug 100 according to the invention, the spark plug 100 has a cylindrical metallic shell 2 whose front end has a ground electrode 1 by means of welding. An inner wall of the metallic shell 2 has a shoulder portion 21, while a rear end of the metallic shell 2 has a thin head 23. Within the metallic shell 2, a tubular insulator 3 is concentrically supported by resting a stepped portion 31 of the insulator 3 on the shoulder portion 21 by way of a packing 22. The thin head 23 is inturned by means of caulking to secure the insulator 3 against removal. An inner space of the insulator 3 serves as an axial bore 32 in which a center electrode 4 is placed by engaging a flange 4B against a shoulder seat 32a provided at an inner wall of the insulator 3. The front end of the center electrode 4 has a constricted end 4A which extends slightly beyond the insulator 3 to form a spark gap (Gp) with the ground electrode 1 through a firing tip described hereinafter. To a rear end of the center electrode 4, is a middle axis 5 connected which has an electrically conductive glass sealant 51, a monolithic resistor 52 and a terminal 53. The spark plug 100 thus structured is secured to a cylinder head of the internal combustion engine (not shown) by way of a gasket 25 and a threaded portion 24 provided at the metallic shell 2.

The center electrode 4 has a clad metal 41 and a heat-conductive core 42 embedded in the clad metal 41 as shown in Fig. 2. The clad metal 41 may be made, for example, of Inconel 600 including iron (Fe) and chromium (Cr)and may include nickel, while the heat-conductive core 42 may be made, for example, of an alloyed metal with copper (Cu) or silver (Ag) as a main component. To a front end surface of 43 of the constricted end 4A, a noble metal firing tip 6 is bonded by way of a laser beam welding. A diameter of the firing tip 6 is the same as the constricted end 4A, and may be, for example, of platinum (Pt), iridium (Ir), Pt-Ir alloy or iridium-based alloy including oxides of rare earth metals. In this instance, a front end 44 of the heat-conductive core 42 is either thermally transferable contact with a rear end 63 of the firing tip 6 or away from the rear end 63 within the range of 1.5 mm.

The laser beam welding is carried out by using YAG (yttrium, aluminum and garnet) laser beams (Lb) with one shot energy as 2 Joules.

The laser beams (Lb) are applied intermittently to a circumferential interface between an front end surface 43 of the constricted end 4A and a rear end 63 of the firing tip 6 as understood by comparing Fig. 2 to Fig. 3. In this instance, the laser beams (Lb) are directed in the same plane as the interface plane between the constricted end 4A and the firing tip 6. As shown at an arrowed circle (X) in Fig. 3, the laser beams (Lb) are shot sufficient times all through their circumferential length to at least partially overlap neighboring shot spots 71 of the welded portion, the laser beams (Lb) causes to form a wedge-shaped welding solidification alloy portion 7 in which the clad metal 41 and the firing tip 6 are fused each other.

In this instance, it is necessary that each front end limit (L1) of the shot spots 71 is away from a front end surface 61 of the firing tip 6 by at least 0.1 mm. This is because a edged corner 62 of the firing tip 6 is rounded by the heat of the laser beams so as to require an increased spark voltage when the each front end limit (L1) of the shot spots 71 extends to the front end surface 61 of the firing tip 6 beyond the limit of 0.1 mm.

The welding solidification alloy portion 7 is such that it has an intermediate physical property (e.g. thermal expansional coefficient) between the clad metal 41 and the firing tip 6. This makes it difficult to fall the firing tip 6 off the clad metal 41 due to the thermal expansional difference between the clad metal 41 and the firing tip 6 when the front end of center electrode 4 is exposed to a high temperature environment.

A dimensional relationship between D, T, L, A, R and B is as follows:

$0.5\ mm \leq D \leq 1.5\ mm$,

$0.3\ mm \leq T \leq 0.8\ mm$,

0.2 mm $\leq$ L $\leq$ 0.5 mm,

R/3 $\leq$ A $\leq$ R, and

0.3 mm $\leq$ B $\leq$ 0.8 mm.

Where

(D) is a diameter of the firing tip 6,

(T) is a thickness of the firing tip 6,

(L) is a length of the constricted end 4A of the center electrode 4,

(A) is a depth of the welding solidification alloy portion 7 penetrated how far from the outer surface of both the constricted end 4A and the firing tip 6,

(R) is a radius of the firing tip 6, and

(B) is a width of the welding solidification alloy portion 7 measured at the outer surface both the constricted end 4A and the firing tip 6.

The reason when the formula 0.5 mm $\leq$ D $\leq$ 1.5 mm is determined is as follows:

Fig. 4 shows a graph how the spark gap changes depending on the diameter (D) of the firing tip 6. The graph is obtained after carrying out an endurance experiment test at full throttle (5000 rpm) for 300 Hrs with the spark plug 100 mounted on an internal combustion engine (six-cylinder, 2000 cc).

As apparent from Fig. 4, the spark discharge concentrates on the firing tip 6 to rapidly increase the spark gap when the diameter (D) of the firing tip 6 is less than 0.5 mm. That is to say, the diameter (D) less than 0.5 mm promptly develops the spark erosion of the firing tip 6 although the voltage required for the spark plug to discharge is reduced with the decrease of the diamter (D).

Meanwhile, the diameter (D) exceeding 1.5 mm causes to worsen the ignitablity by the increased surface area of the firing tip 6, and at the same time, increasing the amount of the noble metal to make it costly.

The reason why the thickness (T) of the firing tip 6 is more than 0.3 mm is as follows:

When the thickness (T) is less than 0.3 mm, the edged corner 62 of the firing tip 6 is rounded at the time of applying the laser beam welding so as to increase the voltage required for the spark plug to discharge as shown in Fig. 5.

The reason why the thickness (T) of the firing tip 6 is less than 0.6 mm is that the amount of the noble metal not involved in the spark-erosion resistance increases to make it costly when the thickness (T) exceeds 0.6 mm.

When the length (L) of the constricted end 4A is less than 0.2 mm, the heat of the laser beam welding is partially drawn from the clad metal 41 to the heat-conductive core 42. This makes it difficult to evenly fuse the interface between the firing tip 6 and the constricted end 4A.

When the length (L) of the constricted end 4A exceeds 0.5 mm, the clad metal 41 is exposed to an increased amount of the laser beam heat so as to develop blowholes or cracks in the clad metal 41 at the time of carrying out the laser beam welding particularly because the clad metal 41 has a melting point smaller than the firing tip 6.

The reason why the formula R/3 $\leq$ A $\leq$ R is obtained is as follows:

Fig. 6 is a graph showing a relationship between the penetrated depth (A) of the welding solidification alloy portion 7 and a repeated number of endurance cycles required to fall the firing tip 6 off the constricted end 4A. The graph is obtained after carrying out the endurance cycles alternately between a full throttle (5000 rpm) for 1 min. and an idle operation for 1 min. with the spark plug 100 mounted on an internal combustion engine (six-cylinder, 2000 cc).

In this instance, the relationship of the depth (A) and the radius (R) is classified into eight cases.

These are A < R/5 (I), A = R/5 ~ R/4 (I), A = R/4 ~ R/3 (III), A = R/3 ~ R/2 (IV), A = R/2 ~ 2R/3 (V), A = 2R/3 ~ 3R/4 (VI), A = 3R/4 ~ R (VII) and A > R (VIII).

As apparent from Fig. 4, the firing tip 6 does not fall off the constricted end 4A even when exposed to 1000 times of the repeated number of endurance cycles upon determining the relationship as A = R/3 ~ R/2 (IV).

In the case of (VIII), it is not desirable to determine as A > R since it is found that blowholes occurs on which the neighboring shot spots 71 overlap although the firing tip 6 does not fall off the constricted end 4A.

The reason why the width (B) of the welding solidification alloy portion 7 is determined as more than 0.3 mm is as follows:

When the width (B) is less than 0.3 mm, a shortage of the laser beams (Lb) fails to satisfy that the penetrated depth (A) is more than 1/5 of the diameter (D) of the firing tip 6. This causes to fall the firing tip 6 off the clad metal 41.

When the width (B) exceeds 0.8 mm, the firing tip 6 is exposed to an increased amount of the laser beam heat so as to melt the edged corner 62 of the firing tip 6. Otherwise, the increased amount of the laser beam heat develops blowholes or cracks in the clad metal 41 at the time of carrying out the laser beam welding particularly because the clad metal 41 has a melting point smaller than the firing tip 6. It is appreciated that the width (B) falls preferably within the range from 0.4 mm to 0.5 mm.

The following is a reason why the front end 44 of the heat-conductive core 42 is either thermally transferable contact with the rear end 63 of the firing tip 6 or away from the rear end 63 within the range of 1.5 mm.

Fig. 7 shows a graph how the spark gap changes depending on a distance (C) between the front end 44 of the core 42 and the rear end 63 of the firing tip 6 as denoted in Fig. 2. The graph is obtained after carrying out an endurance experiment test at full throttle (5000 rpm) for 300 Hrs with the spark plug 100

mounted on an internal combustion engine (six-cylinder, 2000 cc).

As apparent from Fig. 7, the distance (C) exceeding 1.5 mm rapidly increases the spark gap. This is because the firing tip 6 undergoes a considerable amount of the corrosion or erosion due to the shortage of effectively drawing the heat from the firing tip 6 to the heat-conductive core 42.

Figs. 8~11 show modified forms of the invention.

In a first modified form in Fig. 8, the front end surface 43 of the constricted end 4A has a projection head 45 interfit into a recess 64 provided with the rear end 63 of the firing tip 6. This enables to obviate the necessity of provisionally holding the firing tip in place at the time of applying the laser beam welding.

In a second modified form in Fig. 9, the front end surface 43 of the constricted end 4A has a recess 46 into which a projection head 65 is interfit which is provided with the rear end 63 of the firing tip 6. The projection head 65 comes near to the core 42 so that it enables to readily draw the heat from the firing tip 6 to the heat-conductive core 42 at the time of applying the laser beam welding.

In a third modified form in Fig. 10, a cruciform groove 66 is provided on the front end surface 61 of the firing tip 6. This makes it possible to virtually increase the spherical volume between the front end surface 61 and the ground electrode, and thus preventing the spark discharge from inadvertently extinguishing so as to reduce the variation of the discharge voltage with a good ignitability.

In a fourth modified form in Fig. 11, the diameter (D) of the firing tip 6 is smaller than a diameter (Do) of the constricted end 4A. The laser beam welding is applied to an interface between the firing tip 6 and the constricted end 4A all through their circumferential length. This enables to reduce an amount of the noble metal to make it advantageous from the cost-saving viewpoint.

It is noted that an argon welding and electron beam welding may be used instead of the laser beam welding.

It is also noted that the ground electrode may be made in integral with the metallic shell instead of welding it to the metallic shell.

Further, it is appreciated that the ground electrode may be made of a composite column in which a copper core is embedded in a clad metal in the same manner as the center electrode 4 assembled in the embodiment of the invention.

While the invention has been described with reference to the specific embodiments, it is understood that this description is not to be construed in a limiting sense in as much as various modifications and additions to the specific embodiments may be made by skilled artisan without departing from the scope of the invention.

Claims

1. A spark plug (100) comprising a ground electrode (1) and a centre electrode (4) having a front end (4A) with a firing tip (6) welded thereto, the firing tip forming a spark gap with said ground electrode (1), characterised by weld extending around the circumference of the external interface between said front end (4A) and said firing tip (6), and into said centre electrode at said interface.

2. A spark plug (100) according to claim 1, wherein said front end (4A) is constricted as compared with the rest of said centre electrode (4).

3. A spark plug according to one of claims 1 and 2, wherein said firing tip (6) is of generally similar cross-section to the surface of said front end (4A) to which said firing tip (6) is welded.

4. A spark plug according to any one of the preceding claims, wherein in longitudinal cross section along said centre electrode (4) said weld has a generally wedge-shaped cross section.

5. A spark plug according to any one of the preceding claims, where D is a diameter of said firing tip (6), T is a thickness of said firing tip (6), L is a length of said front end (4A) of said centre electrode (4), A is a depth of penetration of said weld (7), R is a radius of said firing tip (6), and B is a width of said weld (7) measured at an outer surface of both said front end (4A) and said firing tip (6), and

   wherein a dimensional relationship between D, T, L, A, R and B is as follows:

   $0.5\ \mathrm{mm} \leqq D \leqq 1.5\ \mathrm{mm}$,
   $0.3\ \mathrm{mm} \leqq T \leqq 0.6\ \mathrm{mm}$,
   $0.2\ \mathrm{mm} \leqq L \leqq 0.5\ \mathrm{mm}$,
   $R/3 \leqq A \leqq R$,
   $0.3\ \mathrm{mm} \leqq B \leqq 0.8\ \mathrm{mm}$.

6. A spark plug according to any one of the preceding claims, wherein the weld comprises a plurality of overlapping neighbouring spot shots (71) whereby the weld extends around the full said circumference.

7. A spark plug (100) according to any one of the preceding claims, wherein a spacing of at least 0.1 mm exists between a front surface of said firing tip (6) and said weld.

8. A spark plug (100) according to any one of the preceding claims, wherein said centre electrode comprises a heat-resistant clad metal (41) and a heat-conductive core (42) embedded in the clad metal (41), and a front end of the heat-conductive

core (42) is either in thermally transferable contact with a rear end surface of said firing tip (6) or within 1.5 mm of the rear end surface of said firing tip (6).

9. A spark plug (100) according to any one of the preceding claims, wherein said firing tip (6) is made of a noble metal and/or the weld is deposited by one of laser beam welding, argon welding and electron beam welding.

10. A method of manufacture of a spark plug with a ground electrode (1) and a center electrode (4) having a front end (4A) with a firing tip (6) thereto and forming a spark gap with said ground electrode (1), wherein said method includes the step of welding said firing tip (6) to said front end (4A) and is characterised by carrying out the welding around the circumference of the external interface between said front end (4A) and said firing tip (6) such that weld extends into said centre electrode (4) at said interface.

Fig.1

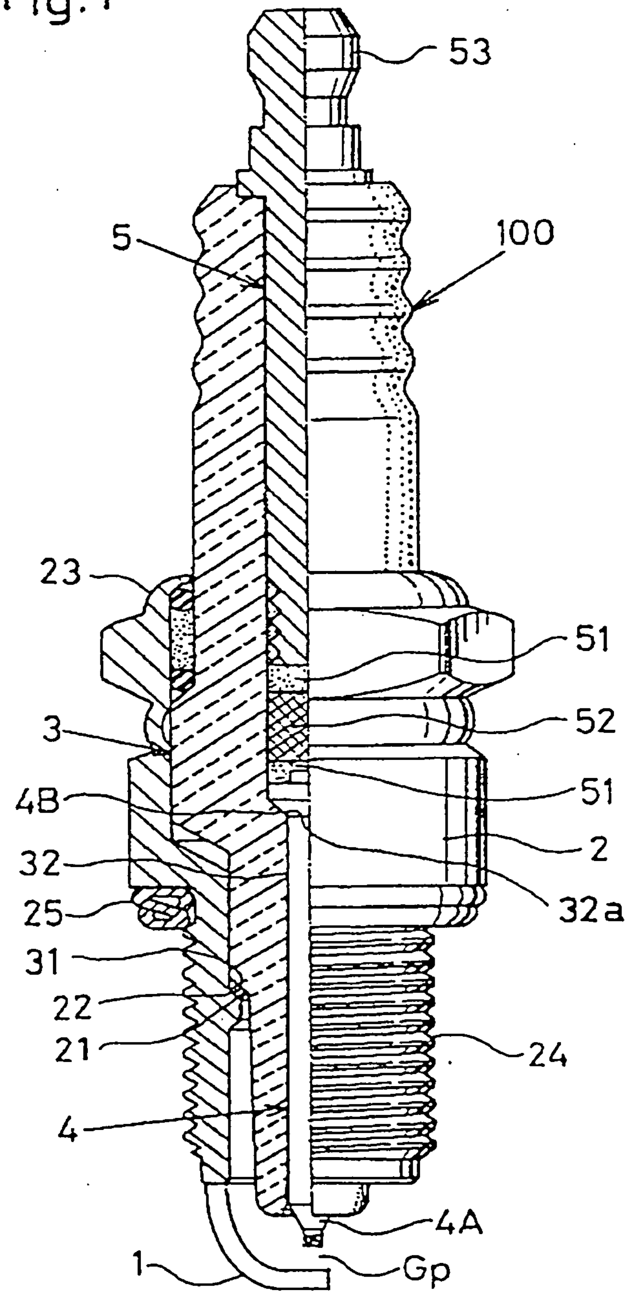


Fig. 2

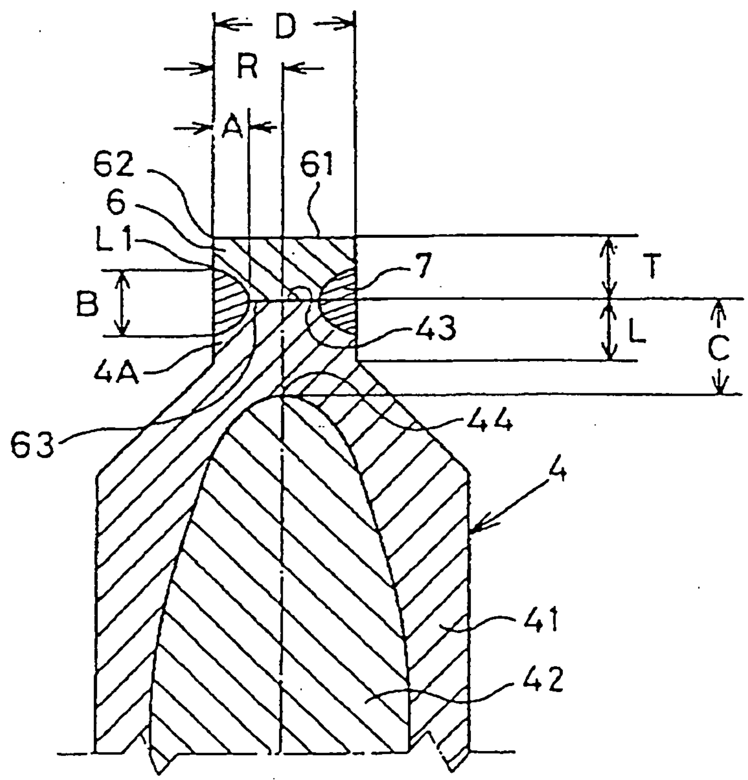


Fig. 3

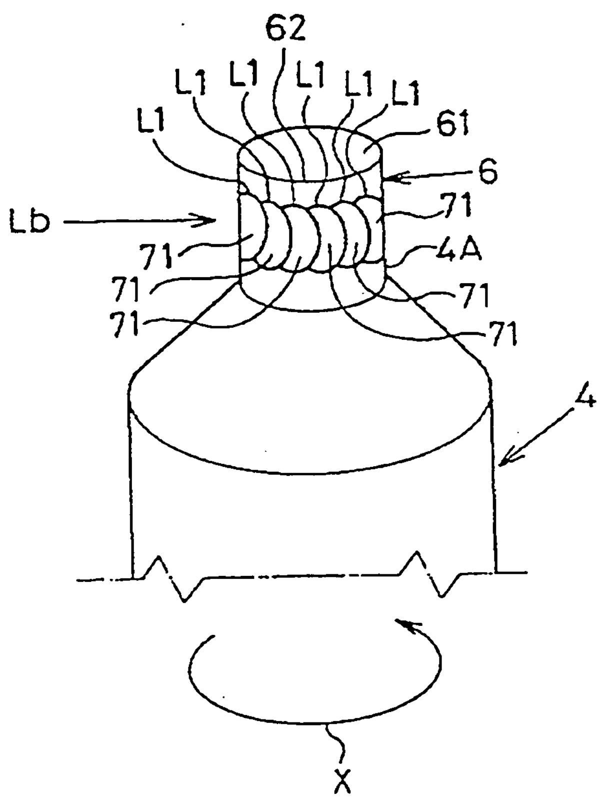


Fig. 4

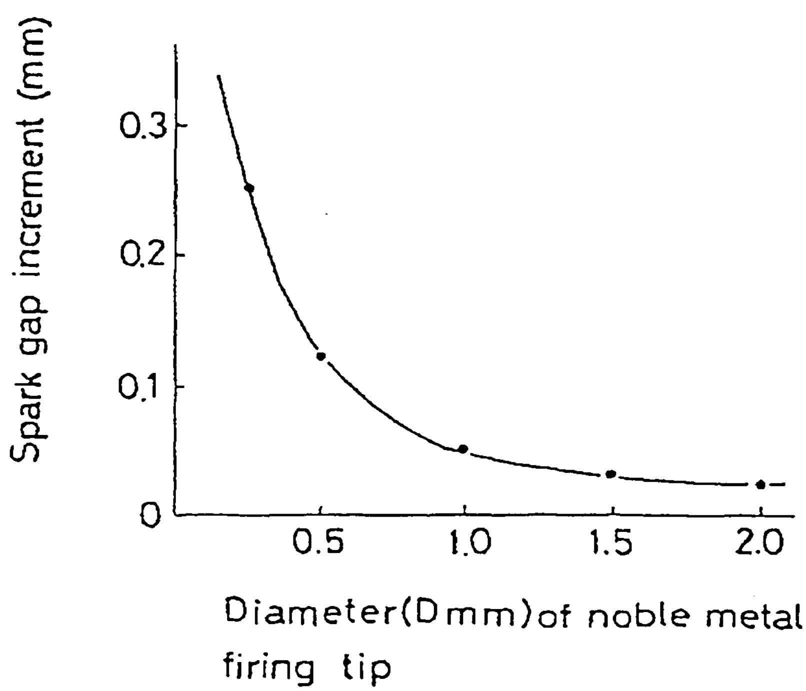

Spark gap increment (mm)
0.3
0.2
0.1
0
0.5
1.0
1.5
2.0
Diameter(Dmm)of noble metal firing tip

Fig. 5

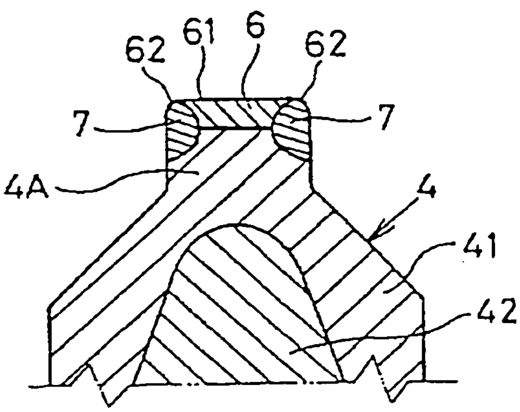


Fig. 6

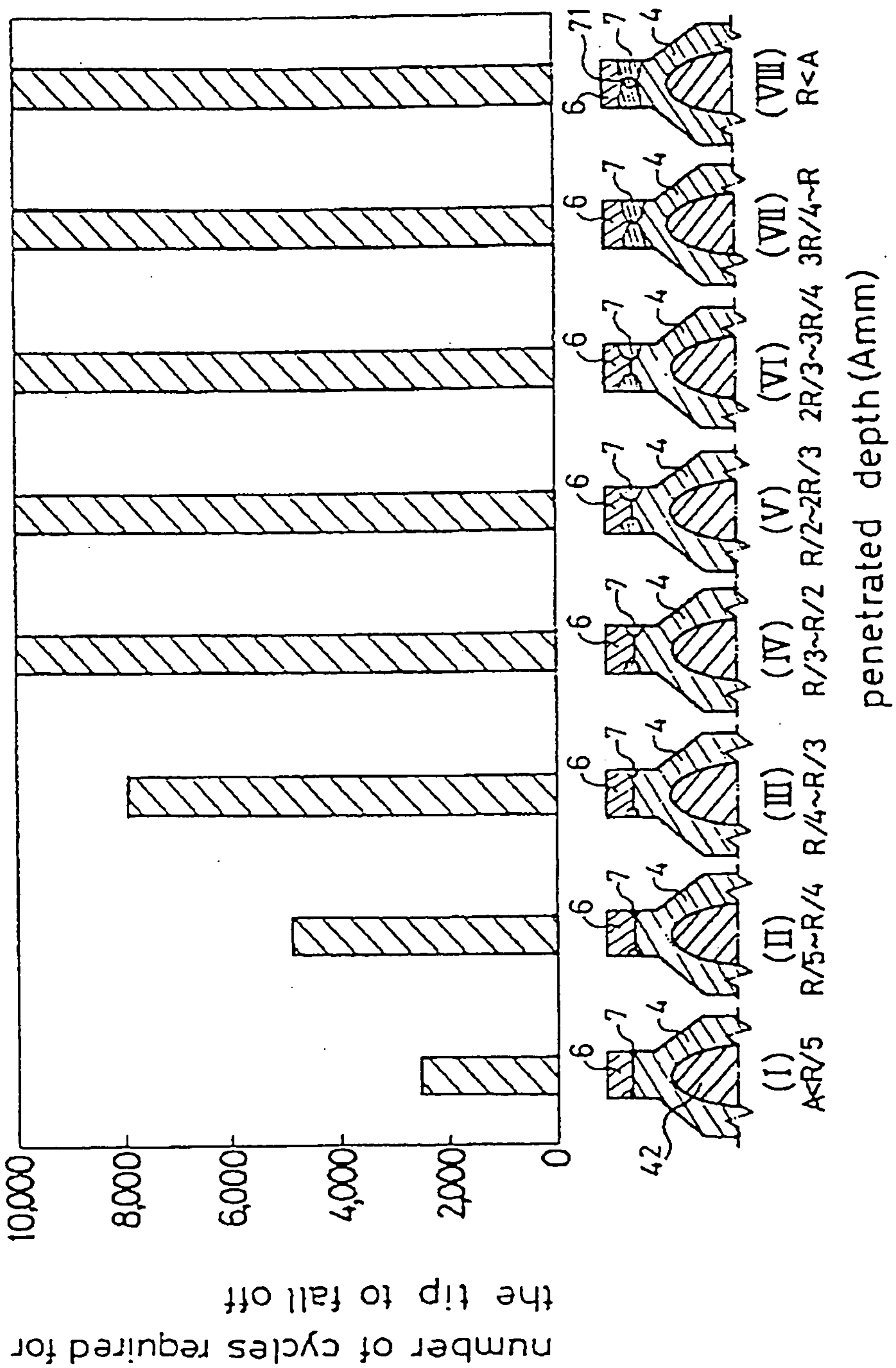

number of cycles required for the tip to fall off
10,000
8,000
6,000
4,000
2,000
0
penetrated depth (Amm)
(I) A<R/5
(II) R/5~R/4
(III) R/4~R/3
(IV) R/3~R/2
(V) R/2~2R/3
(VI) 2R/3~3R/4
(VII) 3R/4~R
(VIII) R<A
6
7
4
42
71

Fig. 7

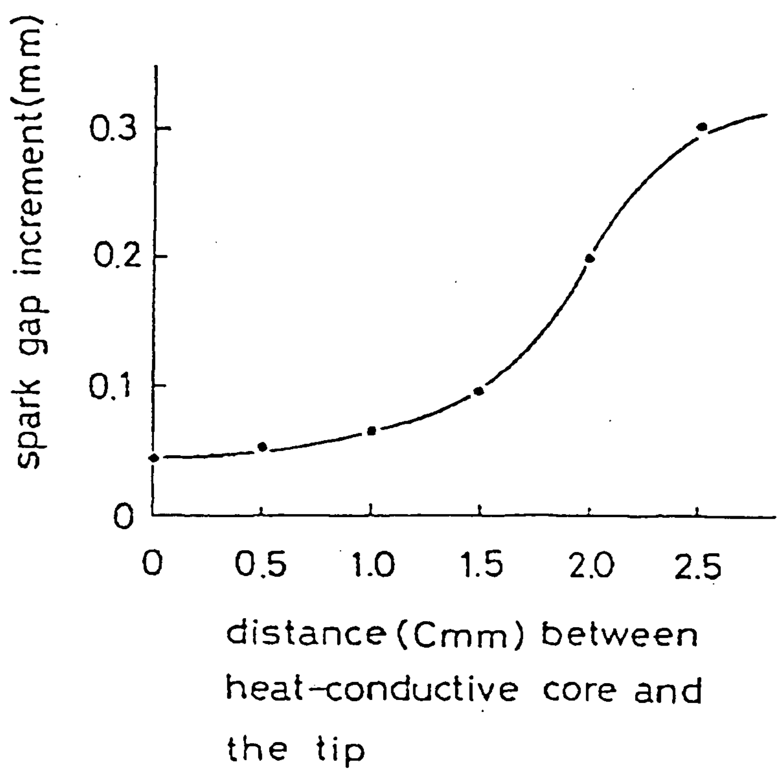

spark gap increment(mm)
0.3
0.2
0.1
0
0
0.5
1.0
1.5
2.0
2.5
distance (Cmm) between
heat-conductive core and
the tip

Fig. 8

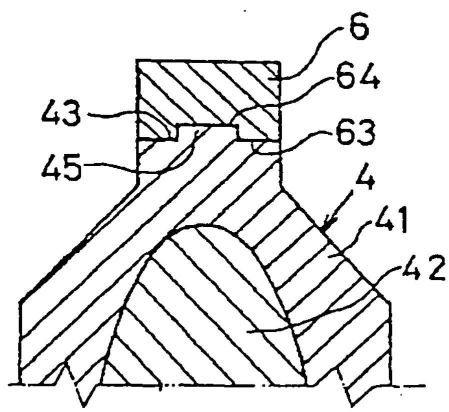


Fig. 9

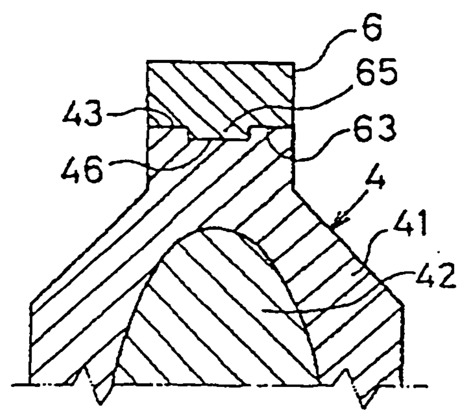


Fig.10

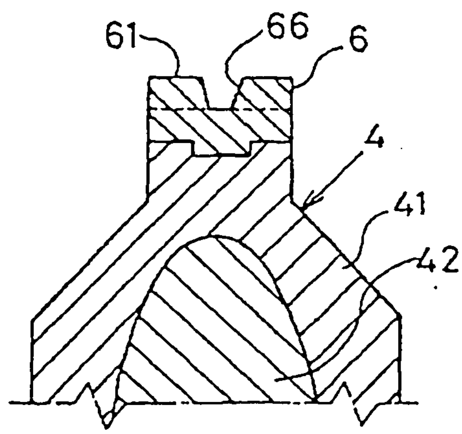
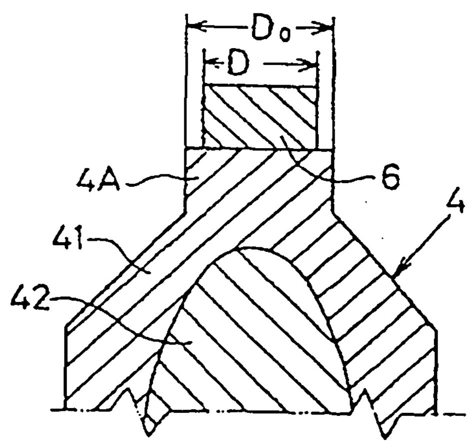


Fig.11



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 93 30 4689

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	WO-A-8 901 717 (ROBERT BOSCH)	1,3,7,9, 10	H01T13/39 H01T21/02
A	* page 5, line 18 - page 7, line 8; figures 2,3 *	6	
A	DE-A-3 132 814 (NIPPONDENSO CO) * page 9, line 20 - page 10, line 2; figures 3-5 *	1-3	
A	FR-A-1 365 880 (ROBERT BOSCH)	4	
D,A	US-A-4 699 600 (KONDO) & JP-B-592 152 (...)		

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

H01T

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	21 SEPTEMBER 1993	BIJN E.A.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P0401)